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TECHNICAL REPORT

Acoustic Doppler Velocity Measurements Collected Near the Southern Nevada Water System Intake, Lake Mead, Nevada.

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Purpose

The Southern Nevada Water Authority requested the Bureau of Reclamation's Water Resources Research Laboratory to collect acoustic Doppler velocity profiles near the Southern Nevada Water System's intake on Saddle Island to determine its withdrawal characteristics from Lake Mead for stratified and destratified reservoir conditions. Understanding the withdrawal characteristics is important to the operations of the Southern Nevada Water System's water treatment facilities.

Introduction

As part of a cooperative effort between the Southern Nevada Water Authority and Reclamation's Lower Colorado Regional Office, this project was initiated to measure currents and water quality profiles near the Saddle Island intake to determine the intake's selective withdrawal characteristics for stratified and destratified reservoir conditions. This report summarizes the current data that was collected July 11, 2001(stratified) and February 21, 2002 (destratified).

Instrumentation

Velocity measurements were collected using an RD Instruments acoustic Doppler current profiler (ADCP) and a Sontek Argonaut acoustic Doppler velocimeter (ADV). Velocity profile data were collected using both instruments; duplicate measurements were collected for quality control purposes. Water quality profiles were collected using SNWS's Hydrolab multi-probe. Locations of the velocity profiles were determined using a Garmin global positioning system (GPS) receiver. Differentially corrected GPS was not used when collecting GPS positions.

ADCP measurements - Velocity profile data were collected using an RD Instruments broadband ADCP, operated from a boat anchored at three points. The ADCP used for this project was a 300 kHz direct-read system which is well suited for this deep water application. The ADCP uses the Doppler shift principle to measure velocities along four acoustic beams projected downward below the boat. The instrument transmits precise acoustic pulses (called pings) and then listens for backscattered acoustic signals reflected from acoustic scatterers in the water column (e.g., organic or inorganic particles). The frequency change of the Doppler shifted backscattered signal is proportional to the velocity of the scattering particle. The ADCP receives and processes the backscatter signals. Each reflected signal is separated from the next by a fixed time. The reflect signals are used to compute velocities from uniformly spaced volumes commonly referred to as depth cells. The four acoustic beams are positioned to 90E apart and are angled at 30E from the vertical. Trigonometric relationships for the acoustic beam configuration are used to resolve the three-dimensional velocity components for each depth cell. Velocities reported by the instrument are the resultant of velocities measured along each of four acoustic beams, rather than a measurement at a single point beneath the instrument. As a result, the accuracy of this measurement technique depends on the homogeneity of the currents over layers of constant depth. In other words, the velocities detected by each beam must be similar in both magnitude and direction for each beam. Typically, horizontal homogeneity of currents in oceans, rivers, and lakes is a reasonable assumption. Care must be taken when collecting near field ADCP measurements at intake structures because they create a nonhomogeneous velocity fields.

Individual ADCP measurements were made within discrete vertical depth cells, or bins, with a height of 100 or 200 centimeters each, yielding a velocity profile from near the surface to near the bed. Velocities could not be measured near the surface because the transducer must be submerged and there is some time delay between the transmit and receive modes of operation. This unmeasured depth is called the blanking distance and is usually 1 to 3 meters deep. Likewise, velocities cannot be measured near the bottom (approximately the last 6 to 10 percent of the depth) due to a phenomenon called side-lobe interference. Side-lobe interference occurs when secondary acoustic beams reflect off the bottom and interfere with backscatter echoes coming from depth cells close to the bottom.

Three orthogonal components of velocity (x, y, z) are measured by the ADCP; an internal compass allows the velocities to be referenced to an earth coordinate system (east, north, up). Tilt sensors are used to correct for any pitch/roll errors in depth measurements. In addition to the velocity data, the ADCP records the depth for each beam. Dedicated bottom tracking pings are collected to track the motion of the boat relative to the channel bottom using the same Doppler shift technique used to measure velocity. This measurement allows the water velocity measurements to be corrected to remove the boat's velocity from the current velocity, and permits tracking the position of the instrument throughout the measurement.

A laptop computer was used to configure the ADCP, control data collection, and store data. A GPS receiver was connected to the laptop computer so continuous GPS positions were recorded simultaneously with the velocity data. GPS positions were not differentially corrected.

Acoustic Doppler Velocimeter (ADV) Measurements - The Argonaut ADV uses Doppler techniques to simultaneously measure three velocity components (x, y, z) of flowing water using a single sampling volume. The orientation of the three velocity components are defined as positive with V_x in the upstream direction, positive V_y is toward the left, and positive V_z is upward. This convention follows a right-handed coordinate system. The ADV sampling volume is located 10 cm (4 in.) below the probe head and is cylindrical in shape (the probe volume is less than 1.7 cm^3). Consequently, the probe head itself had minimal impact on the flow field surrounding the measurement volume. The ADV is equipped with an internal compass and tilt sensors which measure the magnetic heading and 2-axis tilt (up to ±50E from vertical), respectively. The compass allows the ADV to report three-dimensional velocity

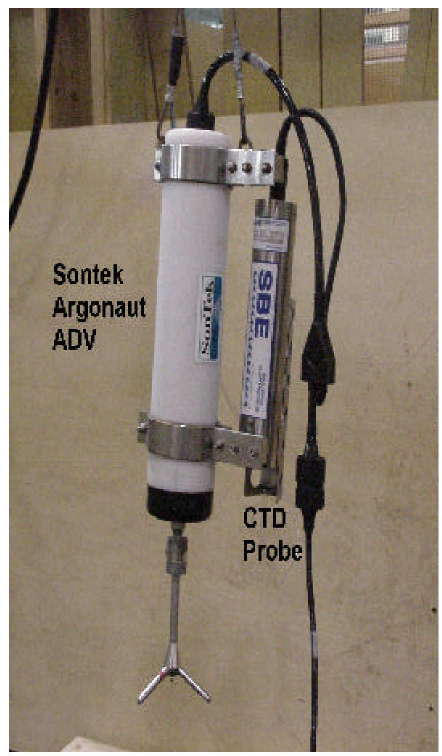

Figure 1. Photo of Sontek Argonaut ADV and SeaBird MicroCAT conductivity and temperature probe.

vectors in earth coordinates (east/north/up). Likewise, the tilt sensors are used to correct the velocity vectors if the probe orientation deviates from vertical. The ADV has a integrated pressure sensor which was used to determine the depth of the velocity measurement.

The Argonaut ADV (figure 1) was selected for this study because it measures velocity at a point. Therefore, ADV data can be used to verify the horizontal homogeneity assumption associated with ADCP measurements, provided lake conditions are calm. In contrast to the ADCP, the ADV cannot resolve boat velocity from its current measurements.

The ADV was coupled with a SeaBird MicroCAT (SBE 37-SI) conductivity and temperature probe into an integrated data collection package. The MicroCAT is a high-accuracy conductivity and temperature recorder with a RS-232 serial interface which transmits data to the Argonaut ADV. MicroCAT data were stored in the ADV's datafile. The MicroCAT's temperature data were used in this study (February 2002 only). SNWA's Hydrolab data were used because they contained more water quality information and were calibrated before the field trip.

The profiling method involved lowering the ADV probe at 5 meter intervals from the surface to near the bottom. Once the ADV was in position, a 90 second sample at a frequency of 1 Hz was collected for a total of 90 velocity measurements. The depth of the ADV probe was measured using the internal pressure sensor. The communications cable was graduated at 5 meter intervals and was used as a reference for positioning the probe. Multiple ADV measurements were averaged for periods when the pressure readings remained steady (i.e. the probe was not moving up or down). ADV data were collected and viewed in real-time via a laptop computer system. Field notes were made when boat wakes and waves might cause a deterioration of data quality.

Field Trips/Data Collection

Two field trips were made to the SNWS Intake at Lake Mead during this project.

Velocity Measurements Collected July 11, 2001 - On Tuesday afternoon, July 10, 2001, I traveled to Las Vegas, Nevada. At 7:00 a.m. on Wednesday morning, I met with Alan Sims and Dan Nguyen from SNWS at their offices. Dan and I went to Reclamation's warehouse to pick up the velocity measurement instrumentation for the field tests. At the Lake Mead Marina, we loaded the equipment on SNWS's water quality sampling boat and departed for Saddle Island. Throughout the day the weather was hot, clear, and calm. We located the centerline of the SNWS intake using a geologic feature on Saddle Island and used the ADCP's bottom tracking ability to determine the horizontal distance from the shore to a point above the intake (calculated using the water surface elevation, El. 1182.5 ft, and USBR project drawing 952-D-24). The horizontal distance was estimated to be 42 meters (138 ft). From this position we traveled a short distance northeast and deployed a three-point anchorage. This position was determined using GPS to be at 36E03.773' N, 114E 47.851' W (figure 2).

ADCP bottom tracking was used to confirm that our anchors were holding the boat in position. For example, during our first set of measurements the boat moved a total of 4 meters (13 ft) during the 45 minutes we collected ADCP data. The anchors along with calm reservoir conditions kept the boat velocities below 2 to 3 cm/sec. The distance and azimuth (degrees clockwise from north) from the profiling location to the intake position (36E03.773' N, 114E 47.888' W taken from a USGS map) were estimated to be 177 ft and 270E, respectively. This position was selected so that all four ADCP beams were located to one side of the intake. It was necessary to position the boat a distance from the intake so that ADCP measurements would include flow from nearly the same direction. If ADCP measurements were collected too close to the intake, individual acoustic beams would measure velocities approaching the intake from different radial directions. I also wanted the boat located in a position where the depths were sufficient to measure the lower boundary of the intake's withdrawal zone. The sampling location on this date had an average depth of about 64 meters. During the tests, the reservoir surface elevation was 1182.5 ft.

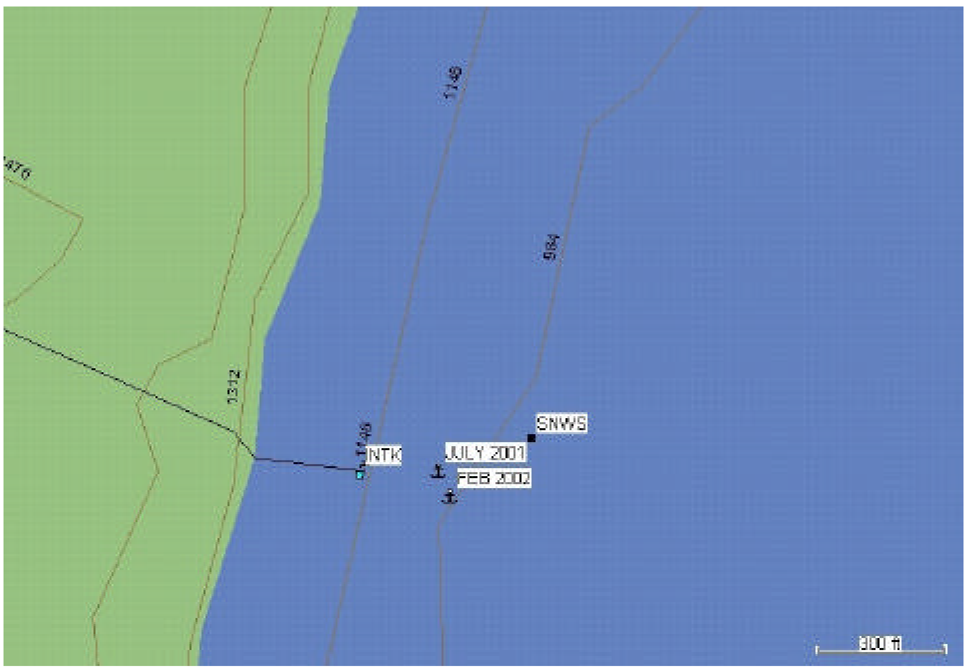

Figure 2. Map of SNWS Intake on Saddle Island, two profiling locations, and SNWS water quality sampling location. (Reference: Garmin Map Source software with U.S. topographic maps for the western United States.)

ADCP and Argonaut ADV velocity profiles were collected at the SNWS intake at Saddle Island. Alan and Dan collected Hydrolab water quality profiles throughout the velocity measurement tests. The test plan called for three flows of 600, 400, and 200 mgd (million gallons per day). We started data collection at 8:30 a.m. at a flow of 565 mgd (874 ft^3/sec) - the maximum pumping rate. I collected ADCP profiles and Argonaut ADV profiles for about one hour. The ADV profile measurements were interrupted by problems attributed to a discharged battery. I recharged the ADV's battery pack for about half an hour and had no more problems for the remainder of the tests. Two additional flowrates were set by the SNWS operators. At about 10:15 a.m. the flow was ramped down to 430 mgd (665 ft^3/sec) and at 12:00 Noon flows were lowered to 234 mgd (362 ft^3/sec). ADCP and ADV data were successfully collected at these two flowrates. During these tests, flows through Hoover Dam steadily increased. For the SNWS pumping plant flows of 565, 430, and 234 mgd average releases from Hoover Dam were 8,100, 10,360, and 15,100 ft^3/sec, respectively.

Velocity Measurements Collected February 21, 2002 - On Wednesday afternoon, February 20, 2002, I traveled to Las Vegas, Nevada and prepared the velocity measurement equipment for data collection. At 7:00 a.m. on Wednesday morning, I met with Peggy Roefer and Alan Sims from SNWS at their offices. At the Lake Mead Marina, Alan and I loaded the equipment on SNWS's water quality sampling boat and departed for Saddle Island. The weather throughout the day was warm, clear, and calm. We located our measurement location using a GPS waypoint stored during the previous field test conducted on July 11, 2001. The distance and azimuth (degrees clockwise from true north) from the profiling location to the intake position (36E03.763' N, 114E 47.845' W from USGS map) were estimated to be 217 ft and 281E, respectively. The profiling position on this date had an average depth of about 65 meters, and the reservoir surface elevation was 1177.3 ft.

The ADCP's bottom tracking was used to confirm that the anchors were holding the boat in a fixed position. The anchors and calm conditions resulted in boat velocities that were typically at or below 3 to 4 cm/sec.

The test plan called for collecting ADCP and Argonaut ADV velocity profiles at the SNWS intake at Saddle Island for *destratified* conditions. Alan Sims attempted to collect water quality profiles but there was a problem with the communication cable so no profiles were collected. However, SNWS collected water quality profiles at the intake on February 19, 2002. The test plan called for three flows of 600, 400, and 200 mgd (million gallons per day). We started data collection at 9:00 a.m. at a flow of 560 mgd (866 ft^3/sec) - the maximum pumping rate. I collected ADCP profiles and Argonaut ADV profiles for a period of one hour. At about 10:00 a.m. the flow was ramped down to 420 mgd (650 ft^3/sec) and at 12:00 Noon flows were lowered to 220 mgd (340 ft^3/sec). For the SNWS pumping plant flows of 560, 420, and 220 mgd, average releases from Hoover Dam were 23,500, 30,100, and 28,000 ft^3/sec, respectively. Hoover Dam flows were about three times higher than flows during the July 2001 measurements.

Data Processing

ADCP and ADV data were processed to produce a set of average velocity profile data for each pumping rate. For ADCP measurements, this involved averaging 300 to 700 independent velocity profile measurements. A program was used to process the ADCP data and report averages and standard deviations for velocity and backscatter signal strength variables. Using the standard deviation of the velocity data, the standard error of each variable was computed by dividing the standard deviation by the square root of the number of good measurements. The total number of good measurements was determined using the following data filtering criteria:

- The velocity ensemble was reported as valid data by the data acquisition program, Transect version 4.05

- Velocities were computed using a 4-beam solution which results in a parameter called an error velocity that was used as an indicator of data quality

- The absolute value of the difference between the two vertical velocity components (error velocity) was less than the velocity magnitude for every depth cell.

- The depth cell being processed had to be above the minimum depth measured by the four acoustic beams. This criterion excludes velocity data at depth cells corrupted by side-lobe interference and velocities computed using 3-beam solutions.

ADV measurements were processed using similar criteria. However, the total number of measurements collected at each depth were much less. Typically, this involved averaging 6 to 8 independent point velocity measurements. Each point velocity measurement recorded by the ADV was an average of 15 measurements collected at 1 Hz. A spreadsheet was used to process the ADV data and to compute averages and standard deviations for velocity, acoustic signal strength, heading, tilt, temperature, depth, and conductivity. The standard error of the average values were computed by dividing the standard deviation of each value by the square root of the number of good measurements. The total number of good measurements was determined using the following data filtering criteria:

- The standard deviation of the depth (pressure) measurement was less than ±4 cm. This criterion was used to exclude data collected when the probe was being lower or raised to a new position.

- The standard error of the velocity magnitude was less than the average velocity magnitude. This criterion was used to remove velocity data that were highly variable.

Test Results - July 11, 2001

Six Hydrolab water quality profiles were collected for thermally-stratified reservoir conditions. Profiles were collected at 8:15, 9:00, 9:50, 10:30, 11:20, and 11:50 a.m. Conductivity profiles showed a spike at about 17 meters below water surface elevation 1182.5 ft (see figure 3). There was also a small reduction dissolved oxygen 17 meters below the water surface. Over the course of the test, the epilimnion warmed slightly and the lower portion of the metalimnion cooled slightly. A review of the SNWS water quality profile collected at their intake site on July 10, 2001 did not have a conductivity spike at 17 meters.

A comparison of ADV and ADCP data showed good agreement considering ADV data includes boat motion that tends to offset velocity magnitudes by 2-4 cm/sec. Figures 4, 5, and 6 present the ADCP velocity profiles collected for pumping rates 234, 430, and 565 million gallons per day, respectively. Horizontal error bars on the plots represent the standard error of the average values of velocity magnitude and direction at each depth. Figure 5 includes a comparison of ADCP and Argonaut ADV measured velocities and illustrates the 1 to 2 cm/sec over-prediction in ADV velocity measurements. According to the layout of the SNWS intake (see drawing 952-D-24 in the appendix), the flow direction along the intake's centerline should be about 270E from north.

However, flow enters the intake radially, so velocity direction will depend on where the ADCP measurements were collected. For example, if the boat were anchored to the north of the intake, a southwesterly current direction would be measured. Furthermore, variations in flow direction can be caused by ambient currents in Boulder Basin, withdrawals from Hoover Dam, local topographic features, and acoustic noise. At the anchorage location used for this set of measurements, the current direction should be about 270E from north (or due west).

Figure 7 shows a combination plot of velocity magnitude and direction data for each pumping rate and it illustrates the repeatability of the ADCP measurements. The velocity magnitude plot shows a peculiar reduction in velocity near the intake elevation, El. 1058 ft. Ideally, a peak velocity should have been measured at the intake elevation. This reduced velocity was observed for all three pumping rates, and the reduced velocity was displaced downward with increasing pumping rates. This interesting withdrawal characteristic may be associated with the currents set up by withdrawals at Hoover Dam which would counteract currents generated by the SNWS intake. For example, the resultant velocity for a 2 cm/sec velocity flowing toward the intake (270E from north) and a 2 cm/sec flowing toward Black Canyon (115E from north) would have a magnitude of 0.9 cm/sec and a direction equal to 192E from north. This computation compares well with velocities measured at a depth near 42 meters which is where the upper cylinder gate at Hoover Dam is located (El. 1045). However, this example computation cannot be verified without collecting detailed velocity measurements outside the SNWS intake withdrawal zone to determine the currents flowing toward the dam.

Selective Withdrawal Modeling - Using water quality profiles collected by SNWS and the U.S. Army Corps of Engineers selective withdrawal program, SELECT, selective withdrawal characteristics were computed for the SNWS intake. The theoretical upper and lower limits of the withdrawal zone for three pumping rates are summarized in Table 1. As expected, the computed withdrawal zone contracts vertically with reduced pumping rates. The actual and computed intake water quality parameters are presented in Table 2.

ADCP data for all three pumping rates indicated an upper limit of withdrawal at a depth of about 30m (see figure 7). This corresponds to an elevation of 330.4 (El. 1084.0 ft) or about 8 m above the SNWS intake; the upper limit of withdrawal was about 12 m below the peak conductivity of 960 FS/cm as shown in figure 3. Figure 8 shows that SELECT computed velocities near the lower limit of withdrawal do not agree with ADCP velocities. One possible explanation for this may be the presence of Hoover Dam withdrawal currents. This explanation is supported by a gradual change in current direction toward Black Canyon for all three pumping rates (see figure 7). Furthermore, another reservoir current with peak velocities in the 4 cm/sec range in a northerly direction was measured at depths between 10 and 20 meters.

Table 1. Summary of SELECT computed withdrawal zone limits for three pumping rates on July 11, 2001. The SNWS intake is located at elevation 322.5 m, and the reservoir elevation was 360.4 m. Figure 7 shows the SELECT and ADCP velocity profiles for three pumping rates.

Selective Withdrawal Limits	565 mgd ($874\ ft^3/sec$) pumping rate	430 mgd ($665\ ft^3/sec$) pumping rate	234 mgd ($362\ ft^3/sec$) pumping rate
Upper Limit Elevation (m)	336.5	335.2	330.0
Lower Limit Elevation (m)	304.0	305.7	309.2
Vertical extent (m)	32.5	29.5	20.8

Table 2. Summary of SELECT computed release water quality parameters and raw water qualities reported by SNWS for July 11, 2001.

Pumping Rate (mgd)	Temperature (EC)		Conductivity (FSiemens/cm)		Dissolved oxygen (mg/l)	
	SELECT	Raw	SELECT	Raw	SELECT	Raw
565	13.5	14.0	922.6	n/a*	6.6	7.2
430	13.5	13.7	922.4	n/a*	6.6	7.3
234	13.4	13.6	921.4	923.9	6.6	7.4

*The SNWS conductivity probe was not reporting reliable values during the 565 and 430 mgd pumping tests.

SELECT modeling results were acceptable for estimating raw water temperatures, conductivity (234 mgd only), and dissolved oxygen (Table 2). However, without knowing more details about where raw water sampling occurs it is difficult to comment on the discrepancies between the SELECT results and the measured water quality parameters. As previously discussed, currents in Boulder Basin appear to modify velocity fields near the intake, which can affect the release water quality as illustrated by small variations in the water quality profiles shown in figure 3.

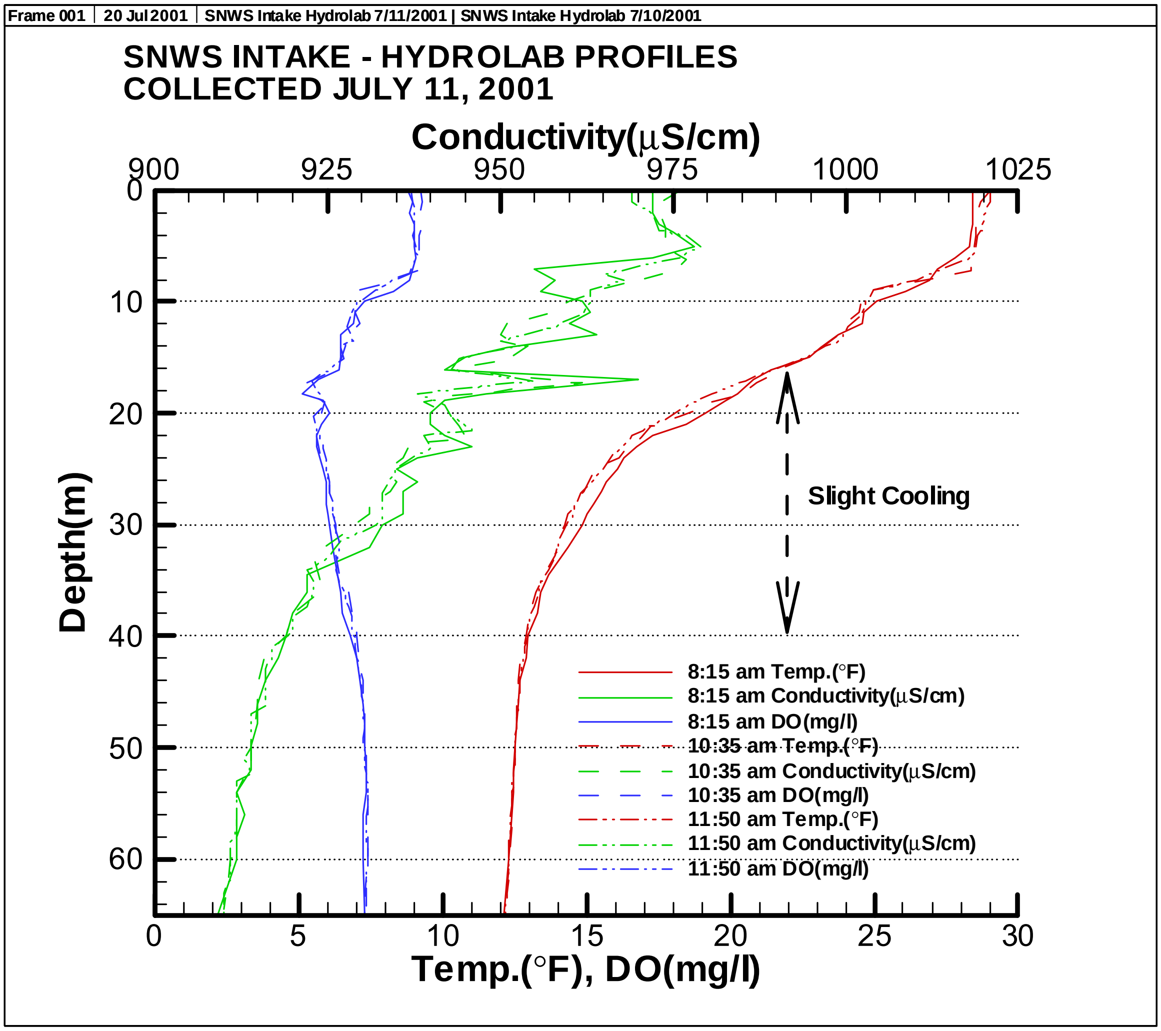

Figure 3. Plot of Hydrolab measured temperature, conductivity, and dissolved oxygen profiles collected near the SNWS intake on Saddle Island, July 11, 2001.

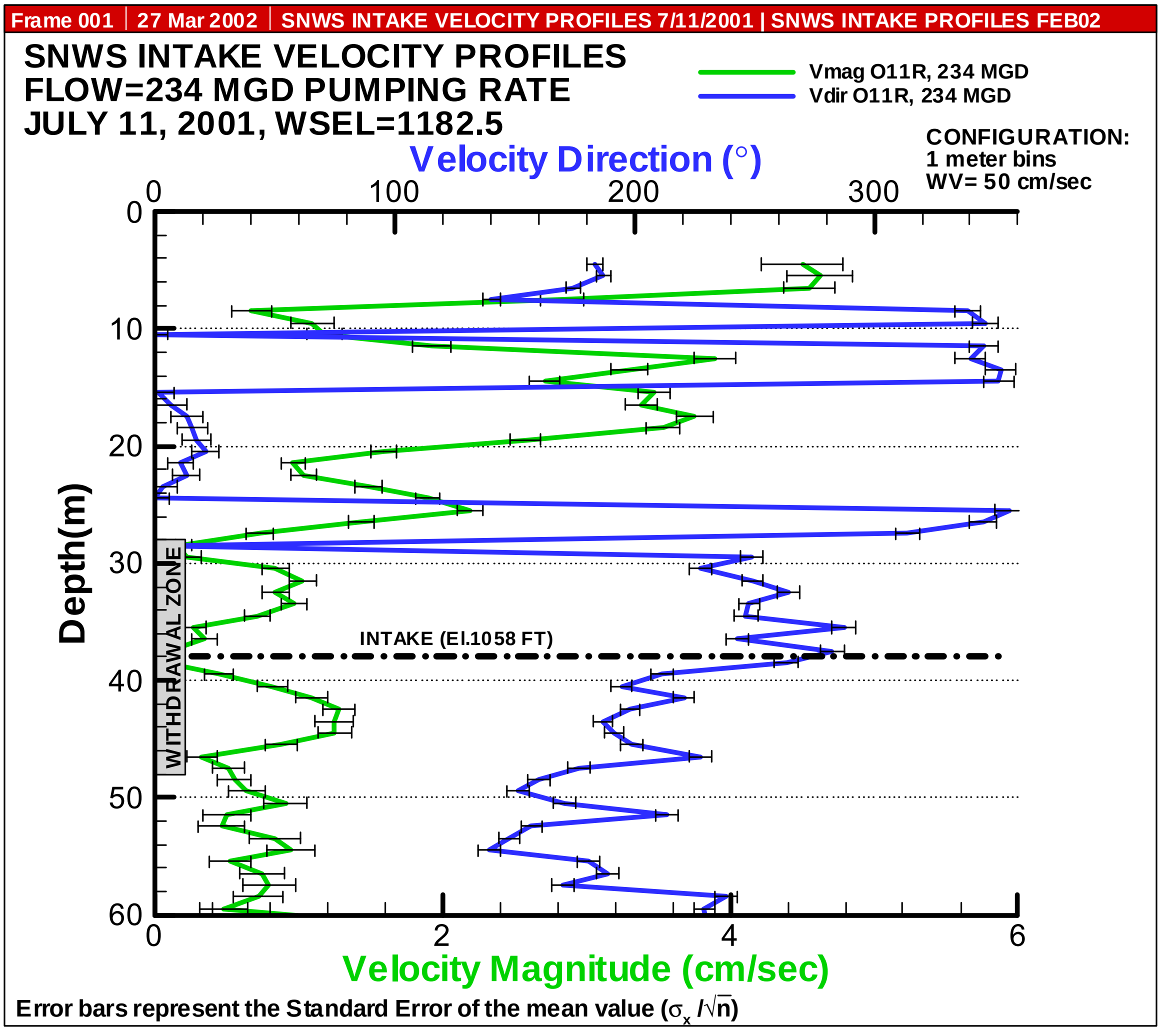

Figure 4. Plot of velocity magnitude and direction for a 234 mgd pumping rate. The horizontal error bars represent the standard error of the average values. Large fluctuations in the direction occur for northerly currents because direction can change from values near 0E and 360E. It is interesting that the highest velocities do not occur within the withdrawal zone.

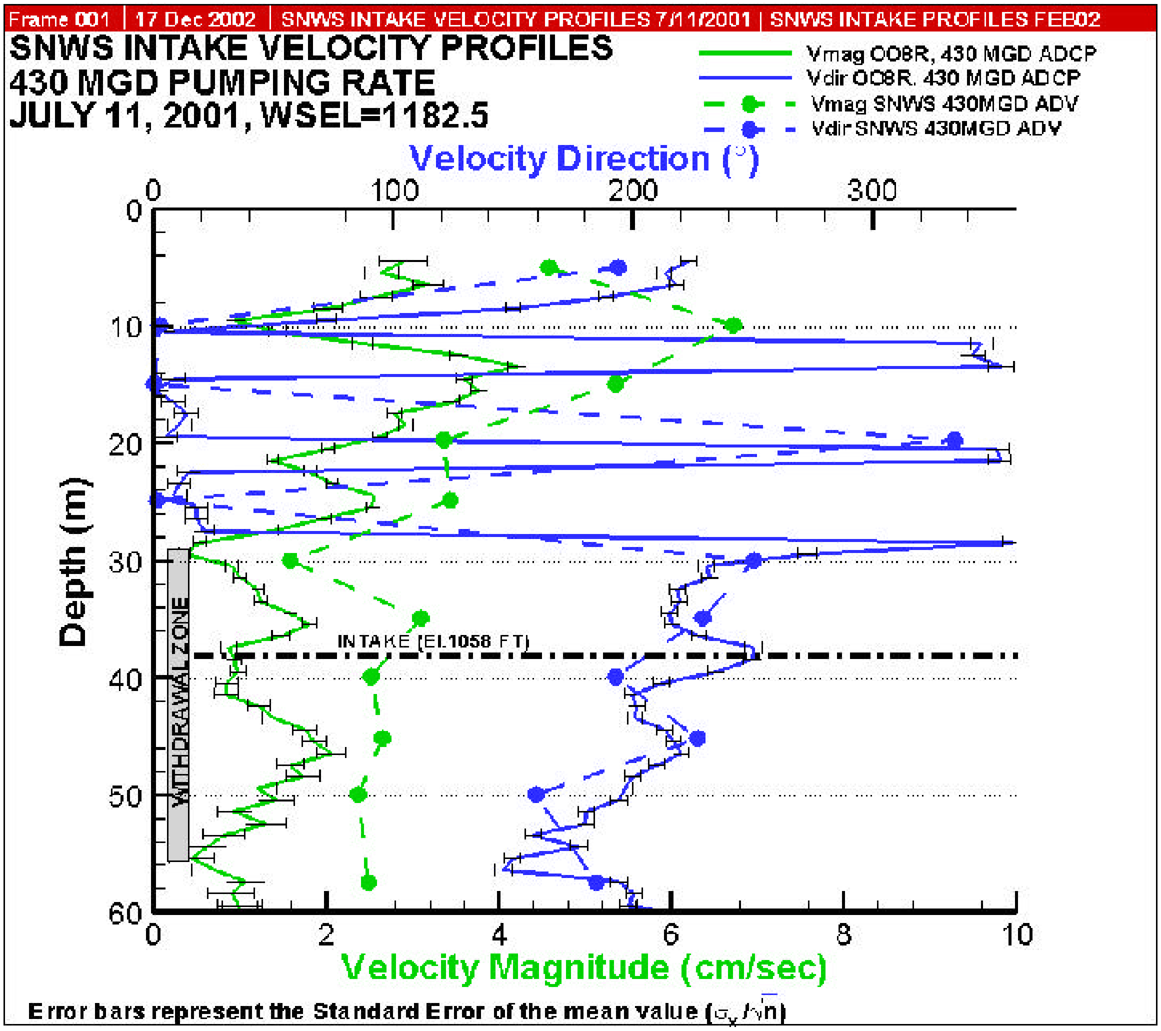

Figure 5. Plot of ADCP and ADV velocity magnitudes and directions for a pumping rate of 430 mgd. For comparable depths, the agreement between the two independent velocity profiles is good in both magnitude and direction considering ADV values include boat velocities, which explains the offset in ADV velocities. The close agreement in velocities validates the ADCPs homogeneous current assumption.

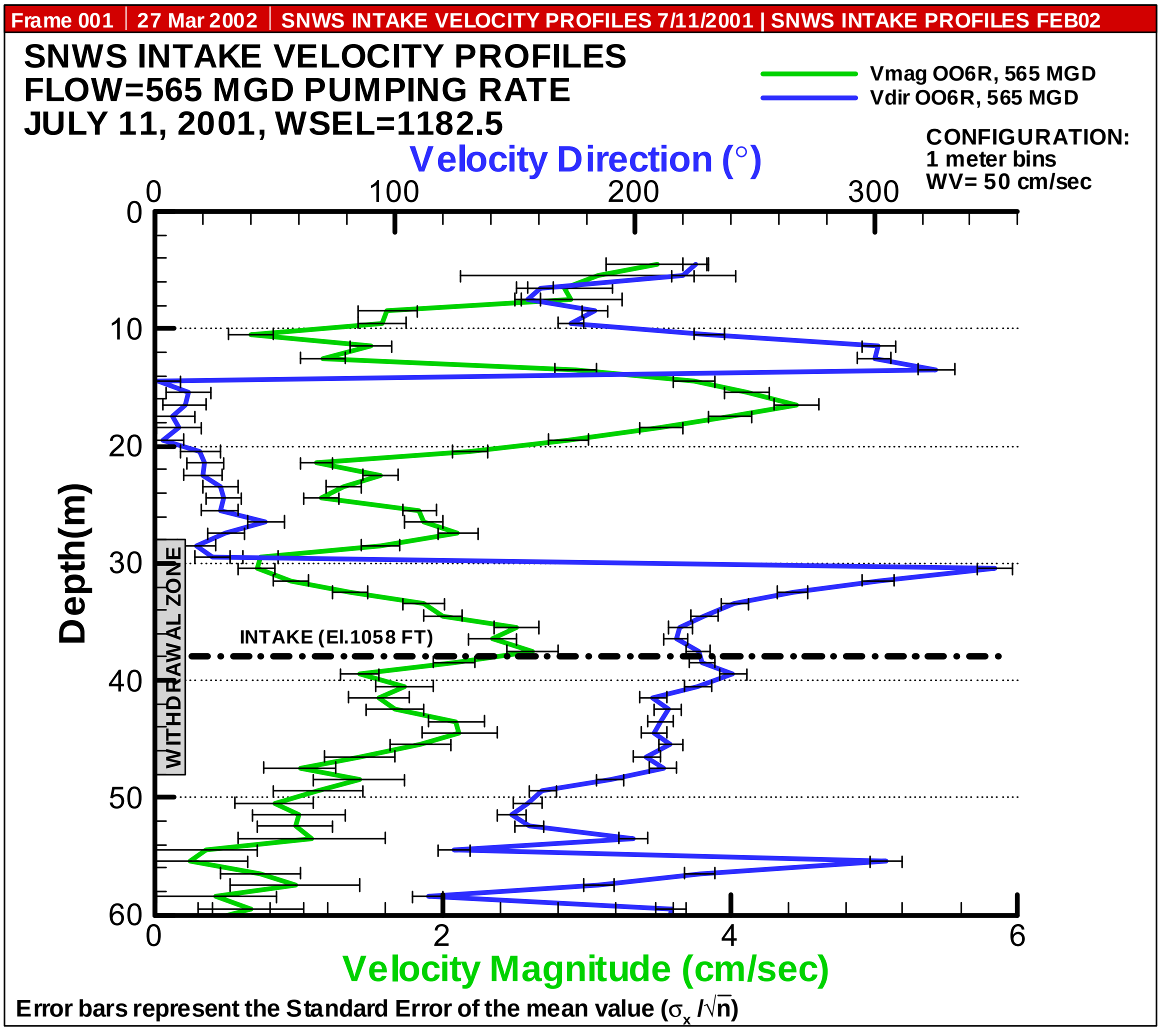

Figure 6. Plot of velocity magnitude and direction for a pumping rate of 565 mgd. The horizontal error bars represent the standard error of the average values. Note the relatively strong northeasterly current between depths of 14 and 22 meters.

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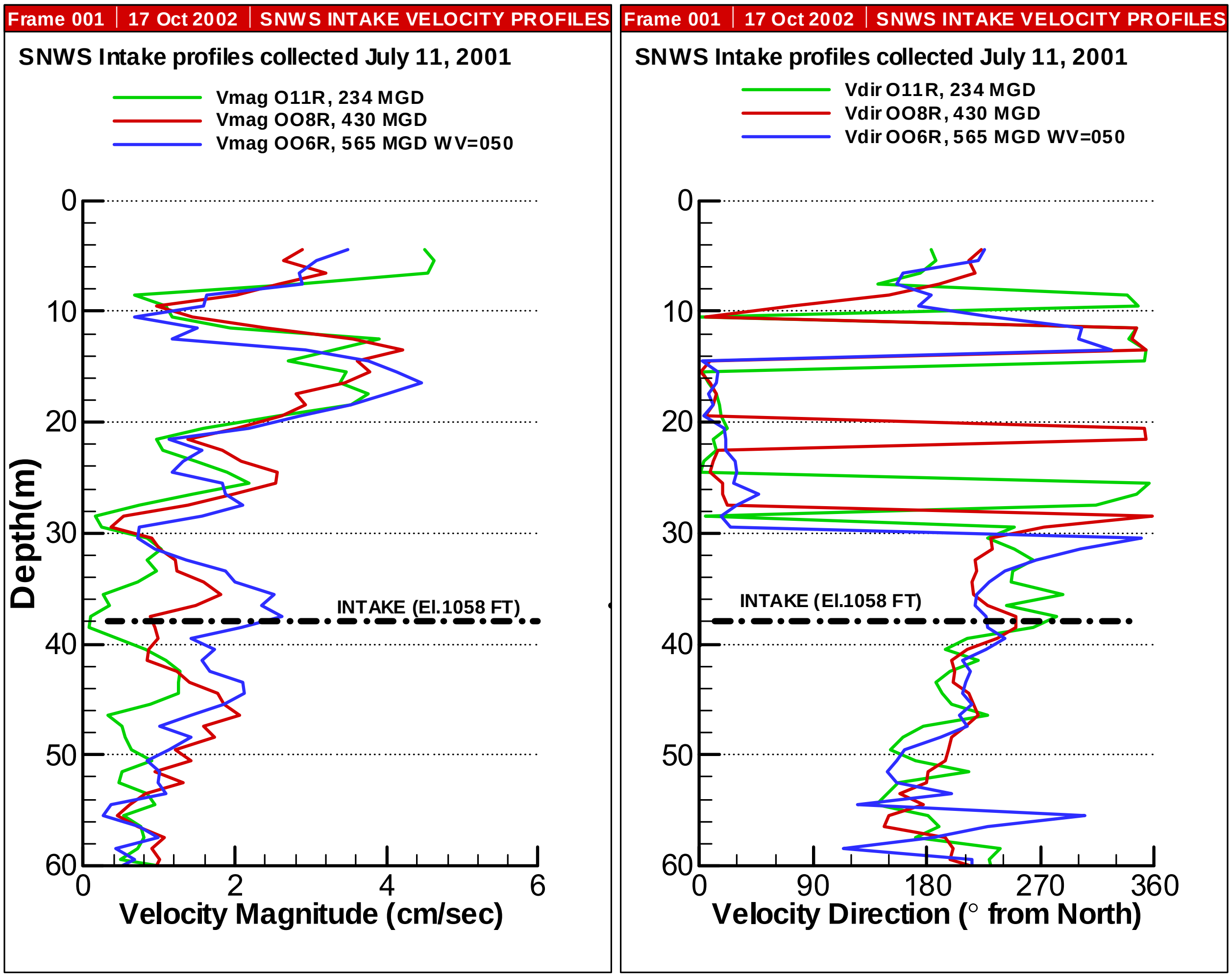

Figure 7. Two plots comparing the velocity magnitudes and directions versus depth for the three pumping rates on July 11, 2001. These plots show relatively close agreement between velocity magnitudes and directions when considering changes in pumping rates. Current direction changes from a westerly direction to a northerly direction at the bottom of the metalimnion. Large fluctuations in the northerly currents (between 8 and 30 meters) result when directions change between 0E and 360E for adjacent depth cells.

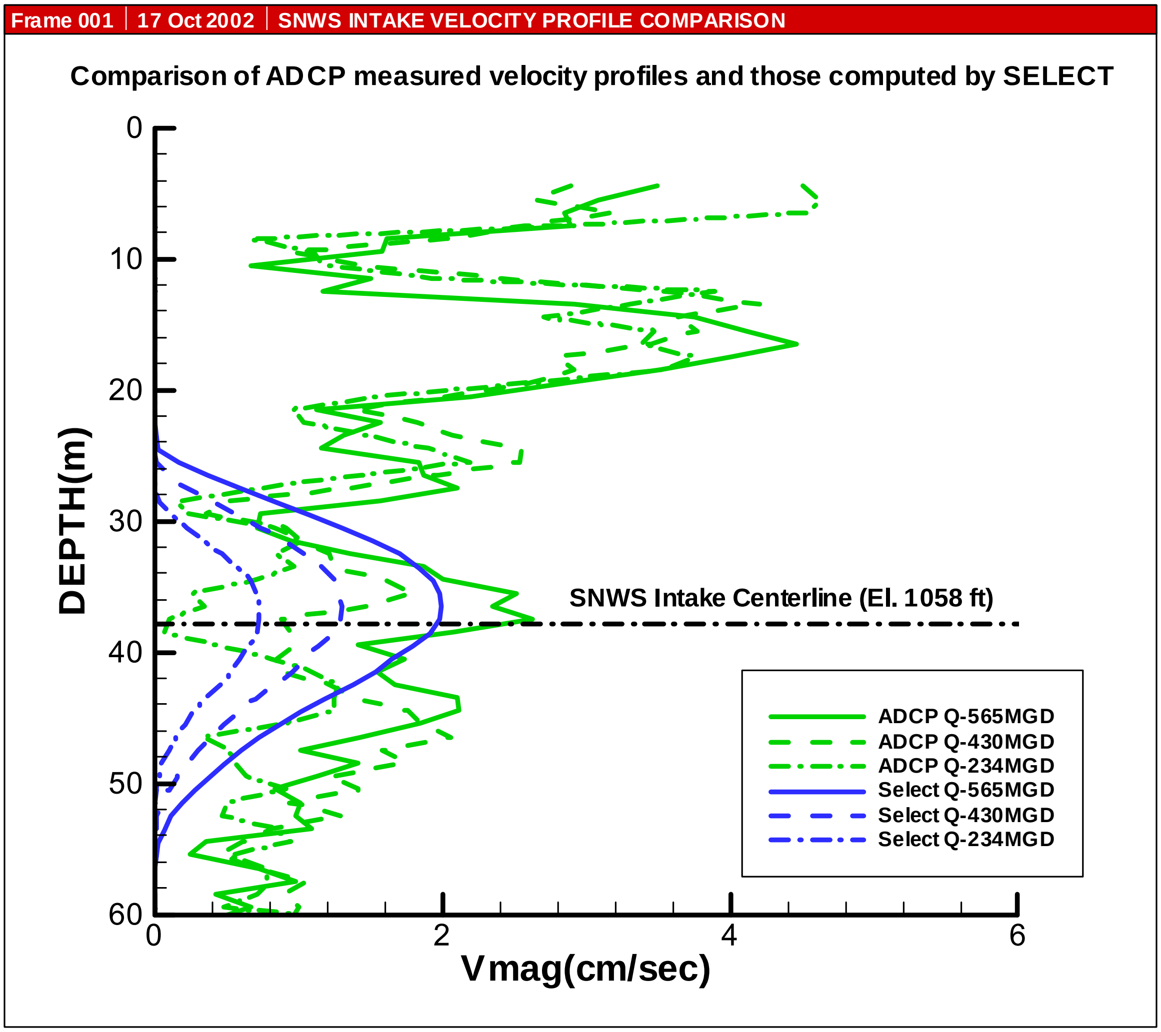

Figure 8. Comparison of ADCP measured and SELECT computed velocity profiles for the SNWS intake for three pumping rates (collected July 11, 2001). With the exception of a dip in velocities near the intake centerline, the agreement in velocity profiles is reasonable.

Test Results - February 21, 2002

Because of Hydrolab equipment problems, no water quality profiles were collected on this day for destratified reservoir conditions. However, the ADV temperature measurements were used to define the temperature profiles for each data set. SNWS did collect a water quality profile at their intake site on February 19, 2002. The SNWS water quality profile data and temperature profiles collected during the tests are shown in figure 9. Temperature profiles collected on February 19 and 21, 2002 showed that near the SNWS intake the reservoir was thermally destratified.
A comparison of ADV and ADCP data showed close agreement considering ADV data includes boat motion that can offset velocity magnitudes by 2 to 4 cm/sec. Figures 10, 11, and 12 present the ADCP velocity profiles collected for pumping rates 220, 420, and 560 million gallons per day, respectively. Horizontal error bars on the plots represent the standard error of the average values

of velocity magnitude and direction at each depth. Figure 11 includes a comparison of ADCP and Argonaut ADV measured velocities and illustrates the 1 to 2 cm/sec over-prediction in ADV velocity measurements. The agreement between the ADV and ADCP measured velocity direction is very good.

Figure 13 shows a combination plot of velocity magnitude and direction data for each pumping rate and illustrates the repeatability of the ADCP measurements. Like the July 2001 measurements, the velocity magnitude plot shows a reduction in velocity near the intake elevation, El. 1058 ft. Ideally, a peak velocity should have been measured at the intake elevation. This reduced velocity was observed for all three pumping rates. Unlike the July 2001 measurements, the velocity directions do not support the "theory" that Hoover Dam withdrawals are responsible for the reduced velocities. It is possible that under destratified conditions the Hoover-generated withdrawal zone velocities were weaker than other currents present in Boulder Basin. The velocity profiles indicate a 1-2 cm/sec current in the northerly direction below El. 1058. This current is moving away from both SNWS and Hoover Dam intakes. Above El. 1058, the current is mostly in a westerly to southwesterly direction as would be expected for flows toward the SNWS intake. Another interesting observation is that the flow directions outside the withdrawal zone are almost exactly opposite from what was observed on July 11, 2001 (see figure 7). These currents usually switched between north and south which is likely caused by Saddle Island's longitudinal axis that runs in the north-south direction. As a result, currents in Boulder Basin which move past Saddle Island are re-directed in a north or south direction depending on the direction of the ambient current. For example, a current moving toward the southwest would be redirected to the south by Saddle Island.

Selective Withdrawal Modeling - Using water quality profiles collected by SNWS, temperature profiles collected using the ADV, and the U.S. Army Corps of Engineers program, SELECT, the selective withdrawal characteristics were computed for the SNWS intake. The upper and lower limits of the withdrawal zone for the three pumping rates are summarized in Table 3. As expected, the computed withdrawal zone contracts vertically with reduced pumping rates. The actual and computed intake water quality parameters are presented in Table 4.

ADCP data for all three pumping rates indicated an upper limit of withdrawal at depths between 14 and 16 m. The criteria for selecting the upper limit of withdrawal were reduced velocity magnitudes and significant change in velocity direction (see figure 13). The upper limit of withdrawal corresponds to El. 1131.8 ft or about 22.4 m above the SNWS intake and agrees closely with the SELECT computed upper limits. The SELECT computed velocities near the upper and lower limits of withdrawal do not match the ADCP measured velocities (see figure 14). A possible explanation maybe the presence of reservoir currents not generated by SNWS pumping plant withdrawals. This explanation is supported by a significant change in the current direction from west to north just below the SNWS intake (El. 1058 ft). However, near the upper limit of withdrawal the current direction changes gradually to the south. Without information on Boulder Basin currents it is difficult to resolve the impact of the reservoir currents.

SELECT modeling results and the raw water temperatures and conductivity are presented in Table 4. The raw water dissolved oxygen sensor was not functioning properly because the reported concentration did not occur anywhere in the water column. The SELECT modeling results were very good. However, this is to be expected considering the reservoir is destratified and the water quality throughout the water column is nearly uniform (see figure 9).

Table 3. Summary of SELECT computed withdrawal zone limits for three pumping rates on February 21, 2002. The SNWS intake is located at elevation 322.5 m, and the reservoir elevation was 358.8 m. Figure 13 shows the SELECT and ADCP velocity profiles for the three pumping rates.

Selective Withdrawal Limits	**560 mgd (866 ft^3/sec) pumping rate**	**420 mgd (650 ft^3/sec) pumping rate**	**220 mgd (340 ft^3/sec) pumping rate**
Upper Limit Elevation (m)	351.1	348.7	342.5
Lower Limit Elevation (m)	296.4	296.4	297.5
Vertical extent (m)	54.7	52.3	45.0

Table 4. Summary of SELECT computed release water quality parameters and raw water qualities reported by SNWS for February 21, 2002.

Pumping Rate (mgd)	**Temperature (EC)**		**Conductivity (FSiemens/cm)**		**Dissolved oxygen (mg/l)**	
	SELECT	**Raw**	**SELECT**	**Raw**	**SELECT**	**Raw**
560	11.9	12.1	928.5	928.1	8.2	10.0*
420	11.9	12.1	928.3	928.1	8.2	10.0*
220	11.9	12.1	928.2	929.0	8.2	10.0*

*This dissolved oxygen concentration is not present anywhere in the water column according to water quality profiles collected by SNWS personnel on February 19, 2002.

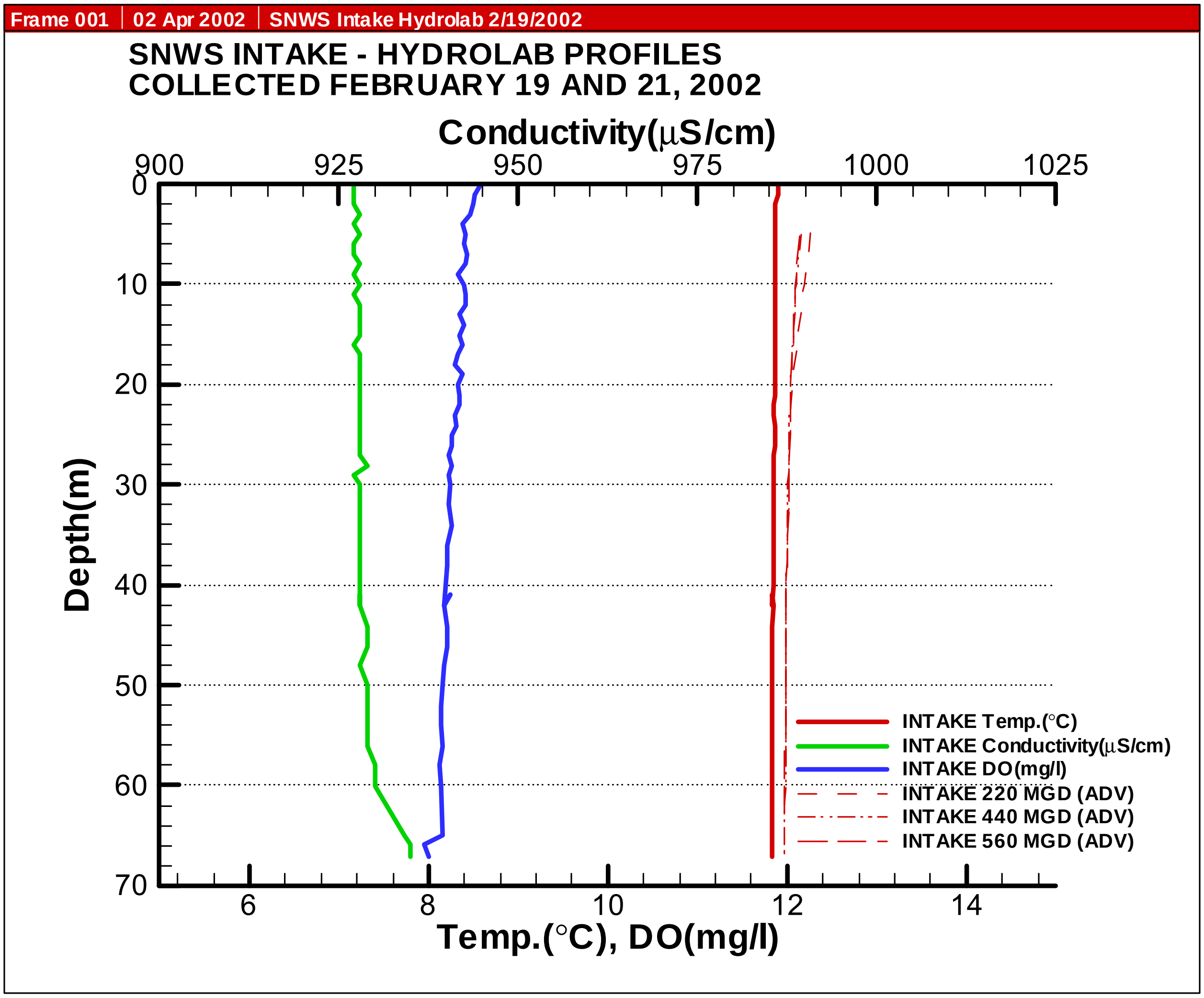

Figure 9. Plot of Hydrolab measured temperature, conductivity, and dissolved oxygen profiles collected near the SNWS intake on Saddle Island, February 19, 2002 and ADV measured temperature profiles collected February 21, 2002.

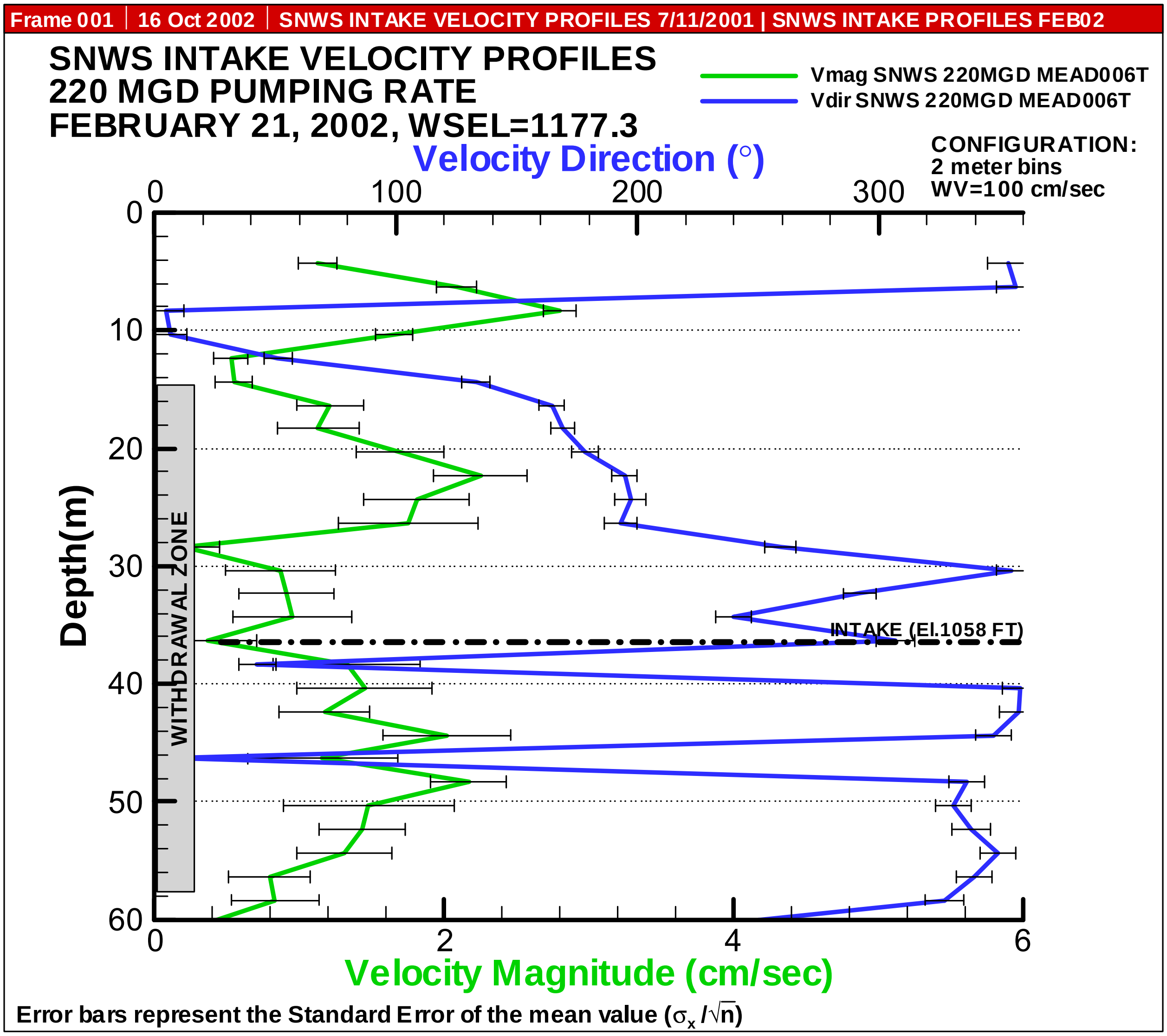

Figure 10. Plot of velocity magnitude and direction for a pumping rate of 220 mgd. The horizontal error bars represent the standard error of the average values. Large fluctuations in the direction values occur for northerly currents because direction can change from values near 0E and 360E.

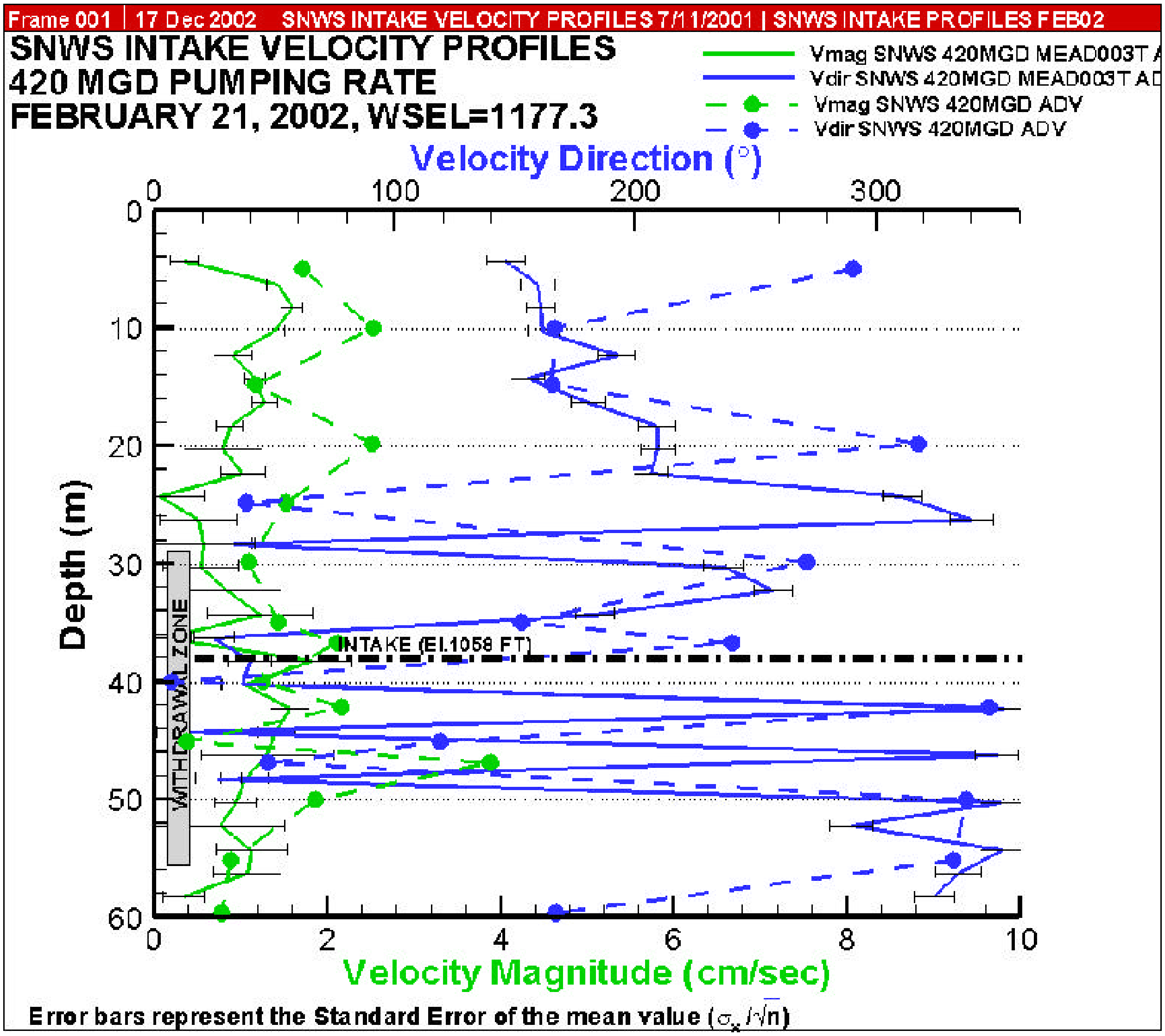

Figure 11. Plot of ADCP and ADV velocity magnitudes and directions for a pumping rate of 420 mgd. For comparable depths the agreement between the two independent velocity profiles is good in both magnitude and direction. ADV values include boat velocities which explains the higher ADV velocities. The good agreement in velocities validates the ADCPs homogeneous current assumption.

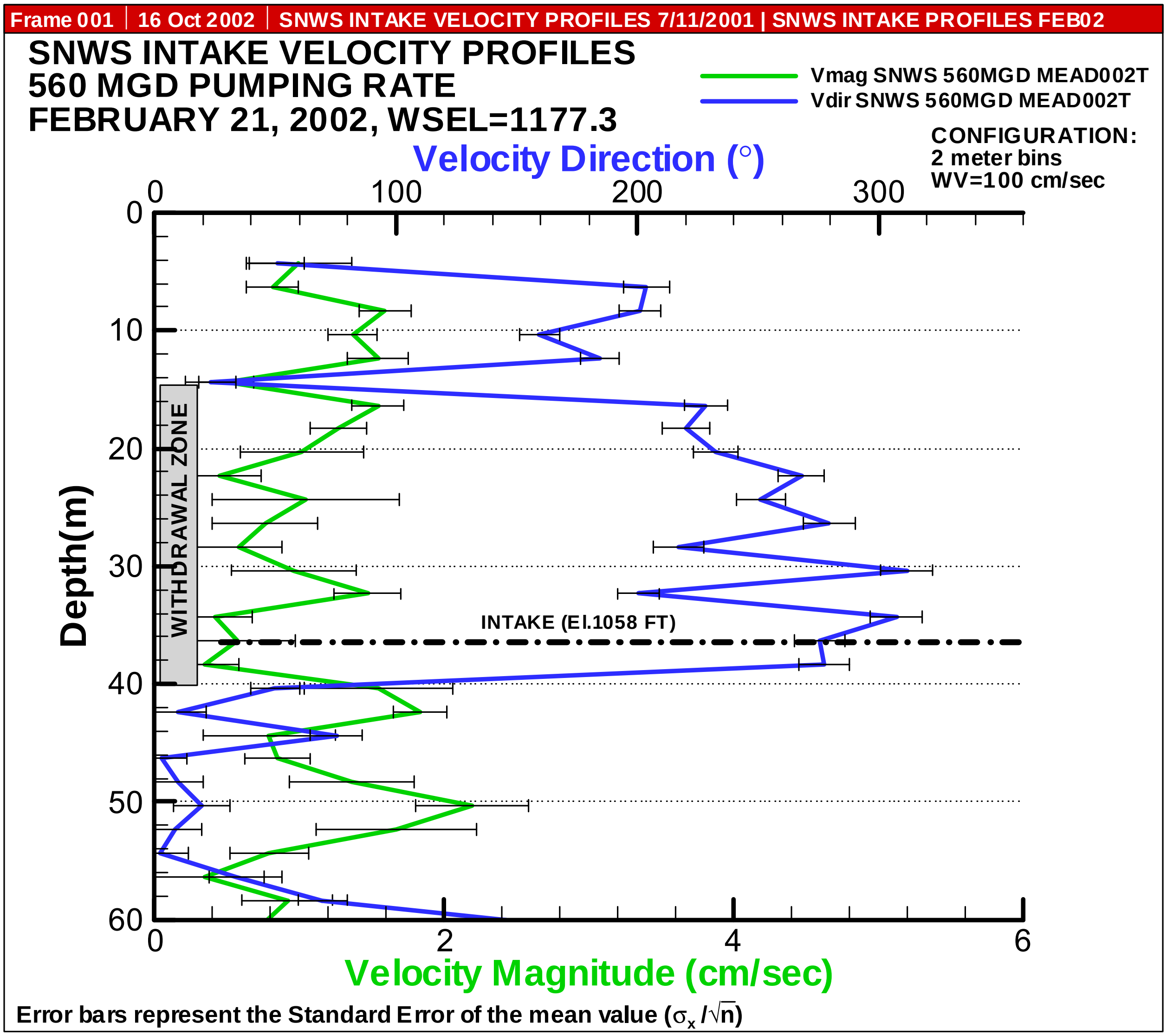

Figure 12. Plot of velocity magnitude and direction for a pumping rate of 560 mgd. The horizontal error bars represent the standard error of the average values. The withdrawal zone was estimated based on the velocity direction data.

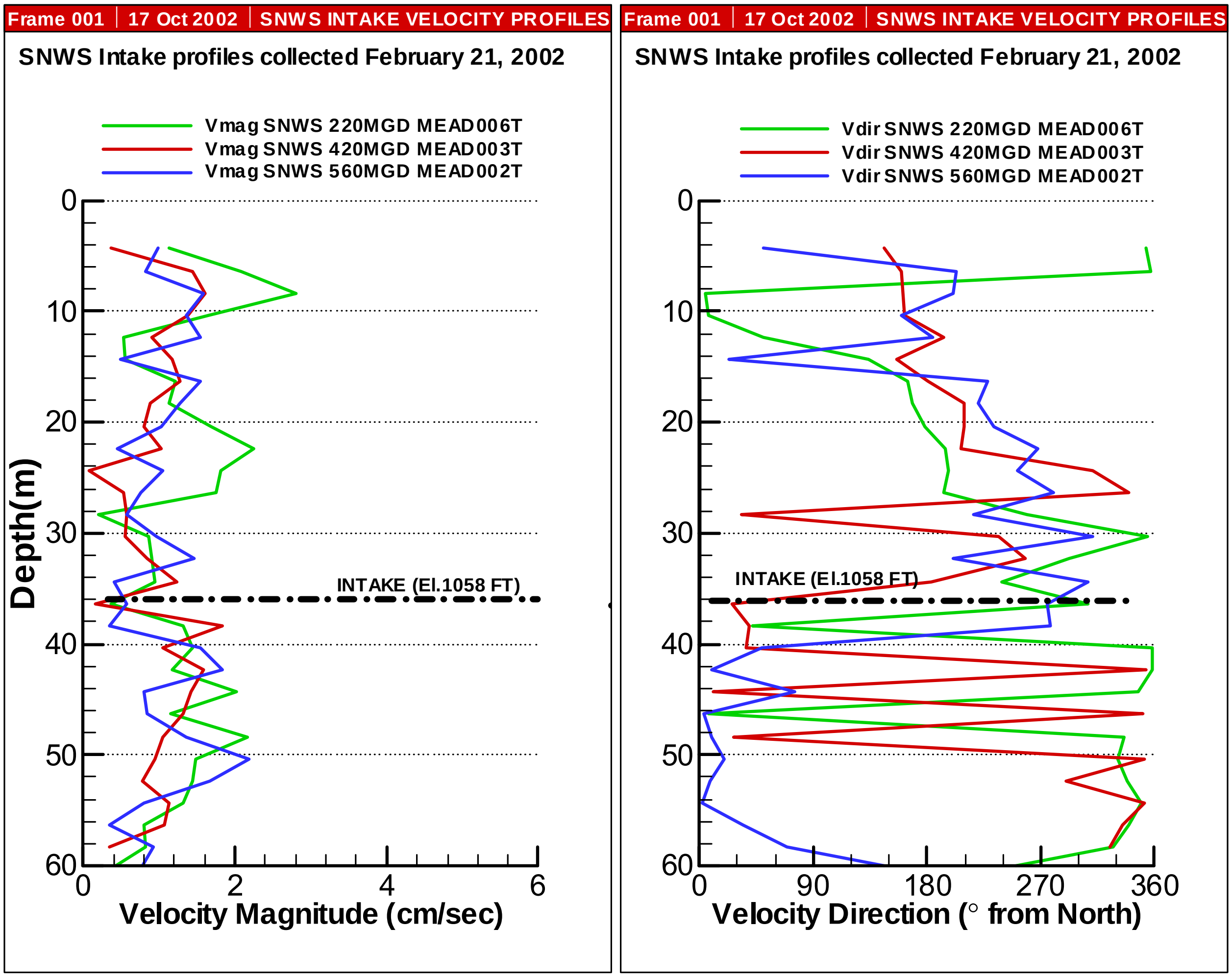

Figure 13. Two plots comparing the velocity magnitudes and directions versus depth for the three pumping rates. These plots show relatively close agreement between velocity magnitudes and directions. However, there does not appear to be a strong correlation between velocity magnitudes and pumping rates. The dip in velocity magnitudes at the intake centerline elevation occurred as it did under stratified conditions. The fluctuations in direction below the intake elevation result from reservoir currents moving in a northerly direction and the values can change between 0E and 360E for adjacent depth cells.

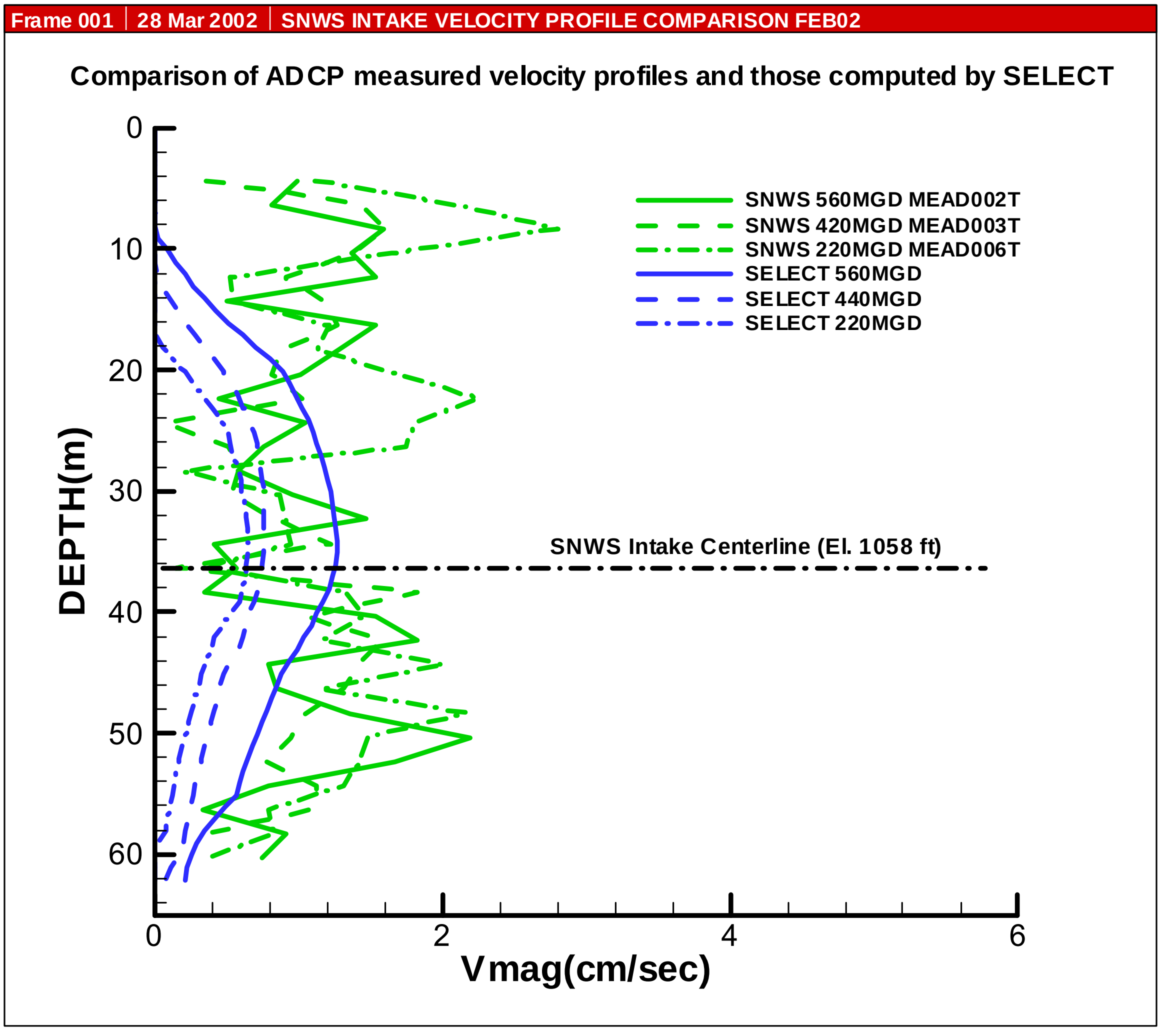

Figure 14. Comparison of ADCP measured and SELECT computed velocity profiles for the SNWS intake for three pumping rates (collected February 21, 2002). Overall the ADCP velocities were higher than those computed using SELECT, and as occurred in July 2001, there were reduced velocities near the intake centerline elevation.

Conclusions and Recommendations

The ADCP measurements collected near the SNWS intake on Saddle Island were successful in measuring a combination of intake-generated currents and ambient currents in Boulder Basin. The ADCP measurements were considered to be a more reliable current measurement technique when compared to an Argonaut ADV. The main drawback with ADV measurements was the inability to resolve the boat motion from the measured currents. Even though efforts to securely anchor the boat were made, boat motion could not be completely eliminated.

Argonaut ADV measurements were used to confirm that the currents near the SNWS intake were horizontally homogeneous at the sampling locations used. The close agreement between the ADCP and ADV data were an important quality assurance metric and provided a level of confidence in the velocity measurements.

Very low velocities were measured accurately with the ADCP by setting a secure three-point anchorage and by collecting hundreds of velocity profiles. Calm weather and no waves were also an important factor. For a constant pumping rate, several hundred ADCP velocities were averaged together using strict data quality criteria to get a representative profile for both thermally stratified and destratified reservoir conditions. The ability to average many profiles together resulted in a very low standard error for the average velocities and other parameters.

In general, ADCP measurements repeatable over the course of each test, even though the pumping rate was changing. However, measurement collected for a stratified reservoir were more repeatable than for the destratified conditions.

Measuring and interpreting the selective withdrawal characteristics of the SNWS intake was complicated by ambient currents in Boulder Basin that appeared to change the velocities within the intake's withdrawal zone. For both tests, there were two or three distinct current layers in addition to the intake's withdrawal zone.

For both field tests, velocity magnitudes measured at intake El. 1058 ft were much smaller than would be expected. For the thermally stratified reservoir, the impacts of Hoover Dam withdrawals appeared to influence the SNWS intake's withdrawal zone. For the destratified reservoir test, the withdrawal zone was poorly defined because velocities were higher both above and below the SNWS intake withdrawal zone. An explanation for this observation was not obvious.

The direction of currents outside the withdrawal zone were difficult to interpret without having additional profile data measured at locations outside the SNWS intake's zone of influence.

Additional velocity profiles at select locations in Boulder Basin may have helped identify the ambient reservoir currents in the vicinity of Saddle Island. The current direction measured near the SNWS intake was observed to switch between north and south. This change in direction was likely caused by Saddle Island's longitudinal axis that runs in a north-south direction. As a result, currents in Boulder Basin that move past Saddle Island are re-directed in a north or south direction depending on the direction of the approaching current. For example, a current moving toward the southwest would be redirected by Saddle Island to a southerly direction.

The accuracy of the SELECT model for computing selective withdrawal characteristics for the SNWS intake is most likely compromised by the presence of ambient reservoir currents because it is a one-dimensional model and has no capability to account for ambient currents.

Appendix

Drawing 952-D-24 Intake Tunnel - Alinement, Profile and Sections

Drawing 952-D-25 Intake Tunnel - Inlet Plan and Sections

Drawing 952-D-249 Intake Tunnel - Safety Net

For PDF Versions: Drawings are not included for security reasons.